Figuring Large Mandrels for Forming X-ray Mirror Substrates

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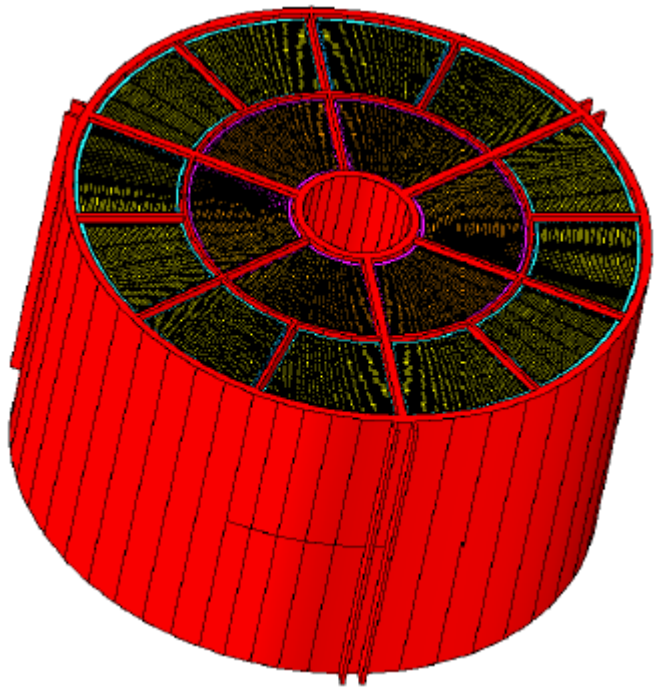
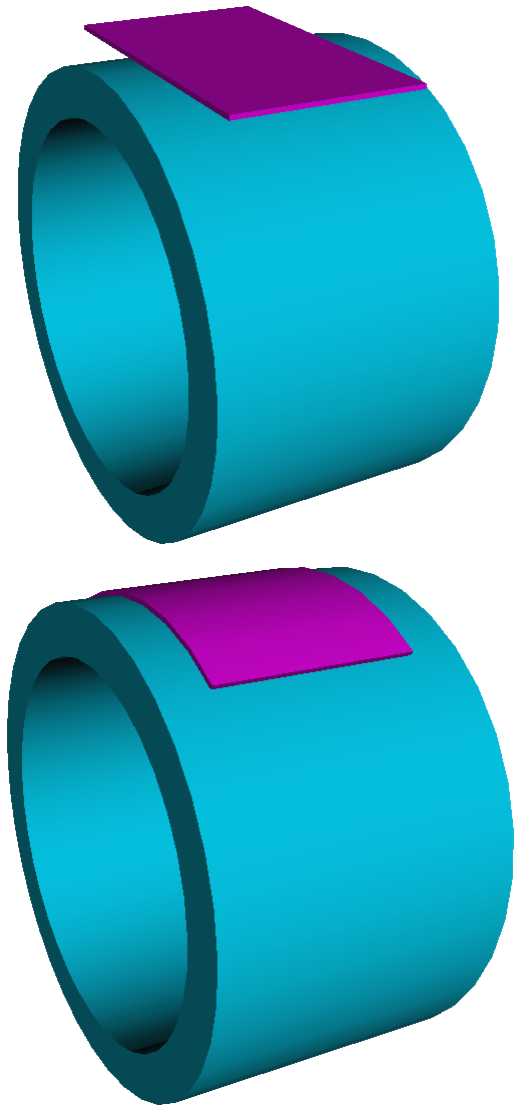
Background: Constellation X Mirrors

- **4 telescope assemblies, each assembly has dimensions:**
  - 1.6m diameter
  - 10m focal length
  - 230 nested shells; inner ring in 6 segments, outer ring in 12 segments
  - Smallest segment 20cmX20cm
  - Largest segment 20cmX40cm
- **Mirror segment specification**
  - 10” HPD imaging
  - Sag (2^{nd} order error) within 0.2μm P-V
  - Slope error after removing sag < 2” RMS
  - Microroughness 6Å or less RMS



How Segments are Made

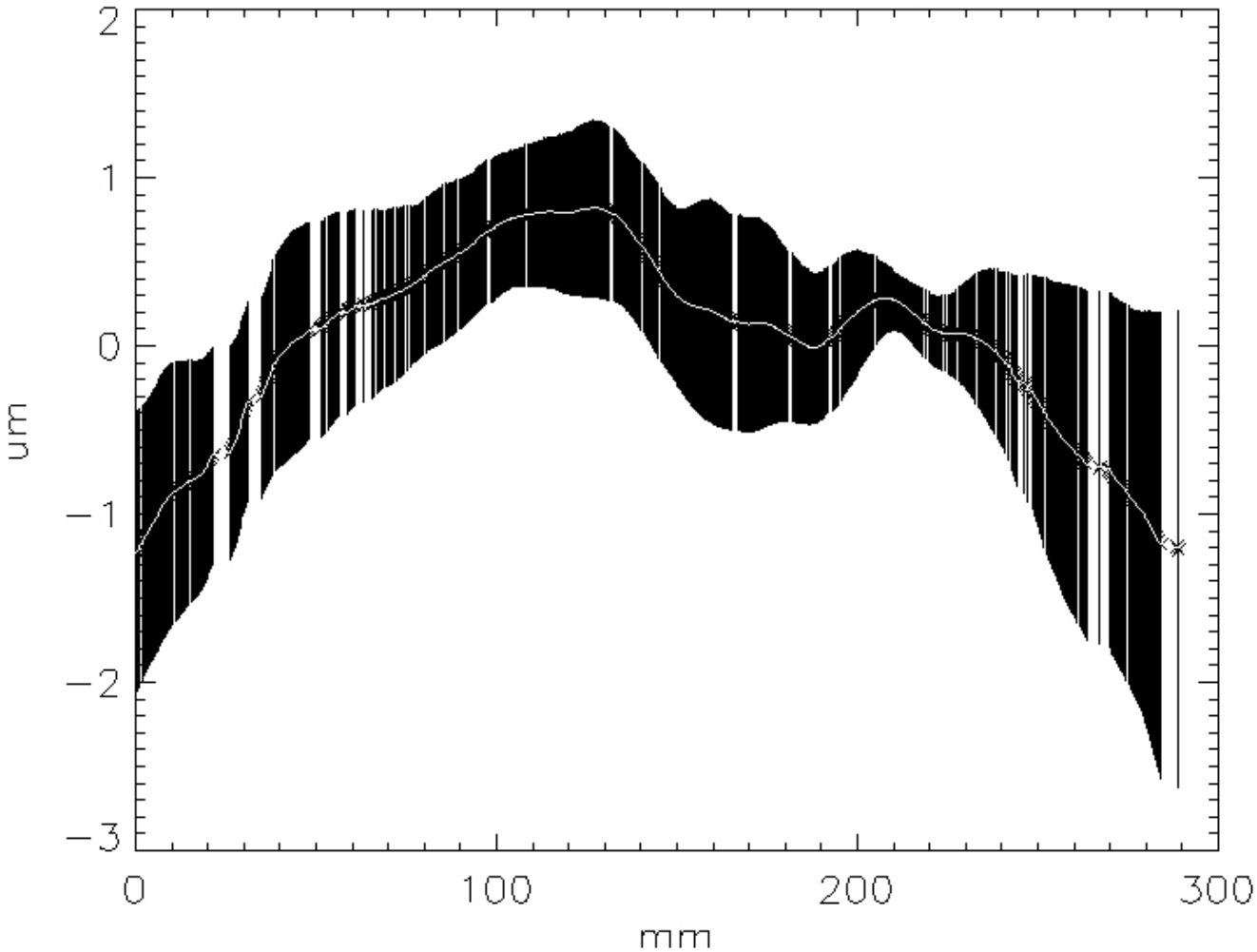


- **Create a substrate by slumping a flat glass sheet onto a forming mandrel, as shown at left. The substrate forms the overall figure for the mirror segment.**
- **Eliminate the high frequency errors of the substrate using an epoxy replication.**
- **The current work is production of quality forming mandrels**
- **Mandrel requirements over quadrant used for slumping:**
  - Sag (2nd order figure error) within 0.2μm P-V
  - Slope error after removing sag < 2" RMS

Optical Assembly Pathfinder Mandrels

- **Set of 2: primary & secondary**
- **Fused silica**
- **500mm diameter**
- **300mm length**
- **25mm wall thickness**
- **“Equal Curvature” figure (similar to Wolter type I)**
- **Forming on exterior surface**

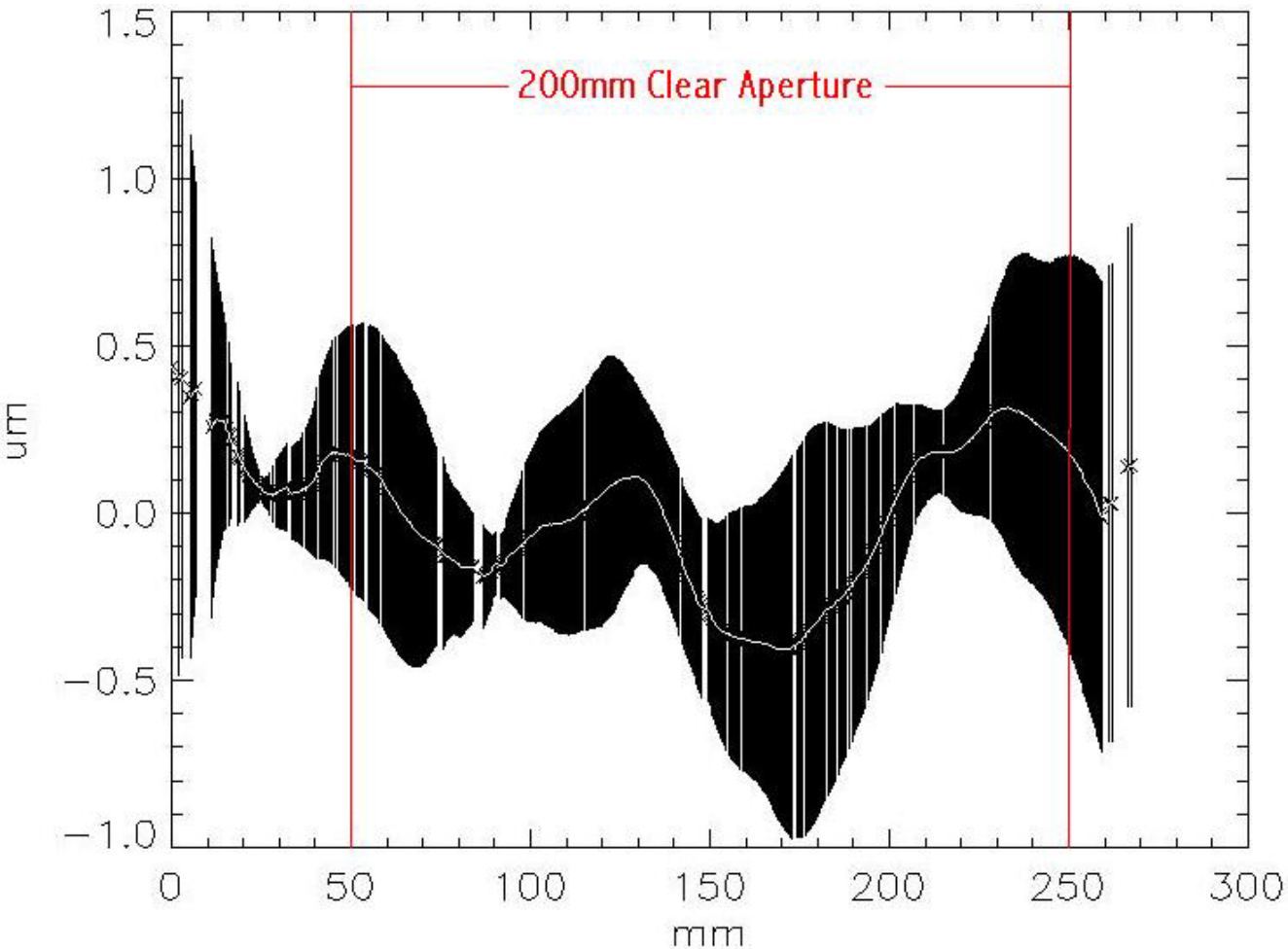
Mandrels as Received: Full Aperture



- **Average of all 12 axial profiles in white**
- **Error bars in black**
- **7.03” RMS slope**
- **1.28µm P-V sag error**
- **6.85” RMS residual slope error with sag removed**

Axial figure error of mandrel F494S at 12 circumferential positions

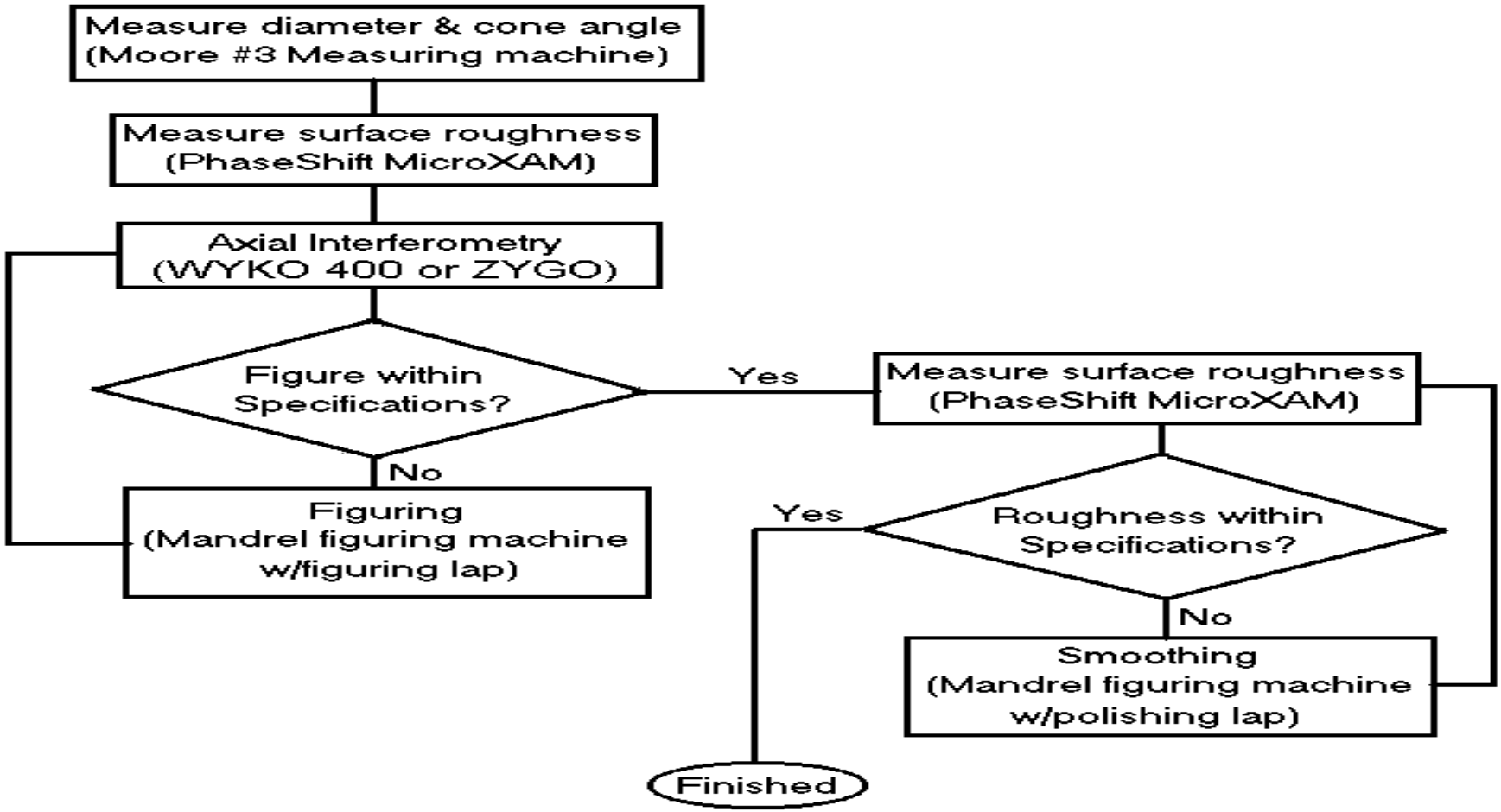
As Received: Best Quadrant, Clear Aperture



- **Average of 4 axial profiles of best quadrant in white**
- **Error bars in black**
- **4.22” RMS slope**
- **0.33µm P-V sag error**
- **4.19” RMS residual slope error with sag removed**

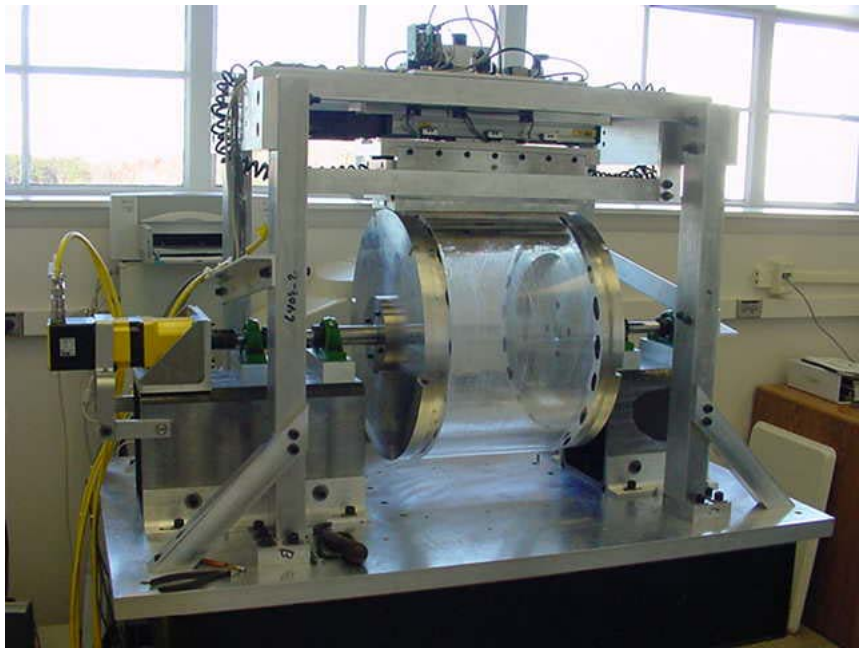
Axial figure error of mandrel F494S in best quadrant, clear aperture

Figuring Process



Flowchart of Process

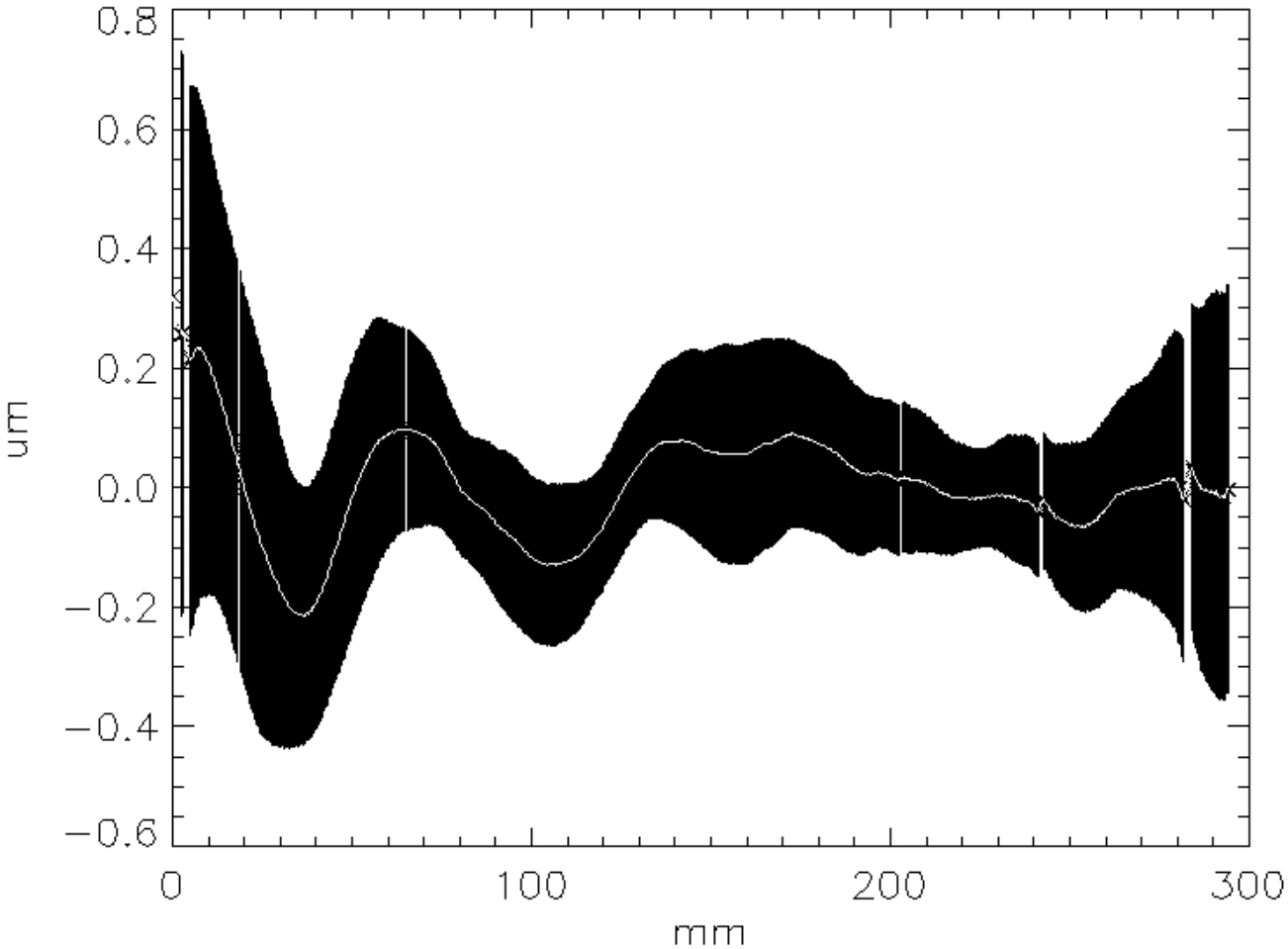
Figuring Equipment



Custom machine that rotates mandrel about axis of symmetry and drives tool axially along mandrel. Computer control on both axes allows variable speed of mandrel and tool which can be varied during a run if required.

Current process uses pitch lap which is shaved to remove less material at axial positions which are low. Mandrel rotated at constant slow speed, and tool driven back and forth in oscillatory motion at rapid rate to figure out axial errors.

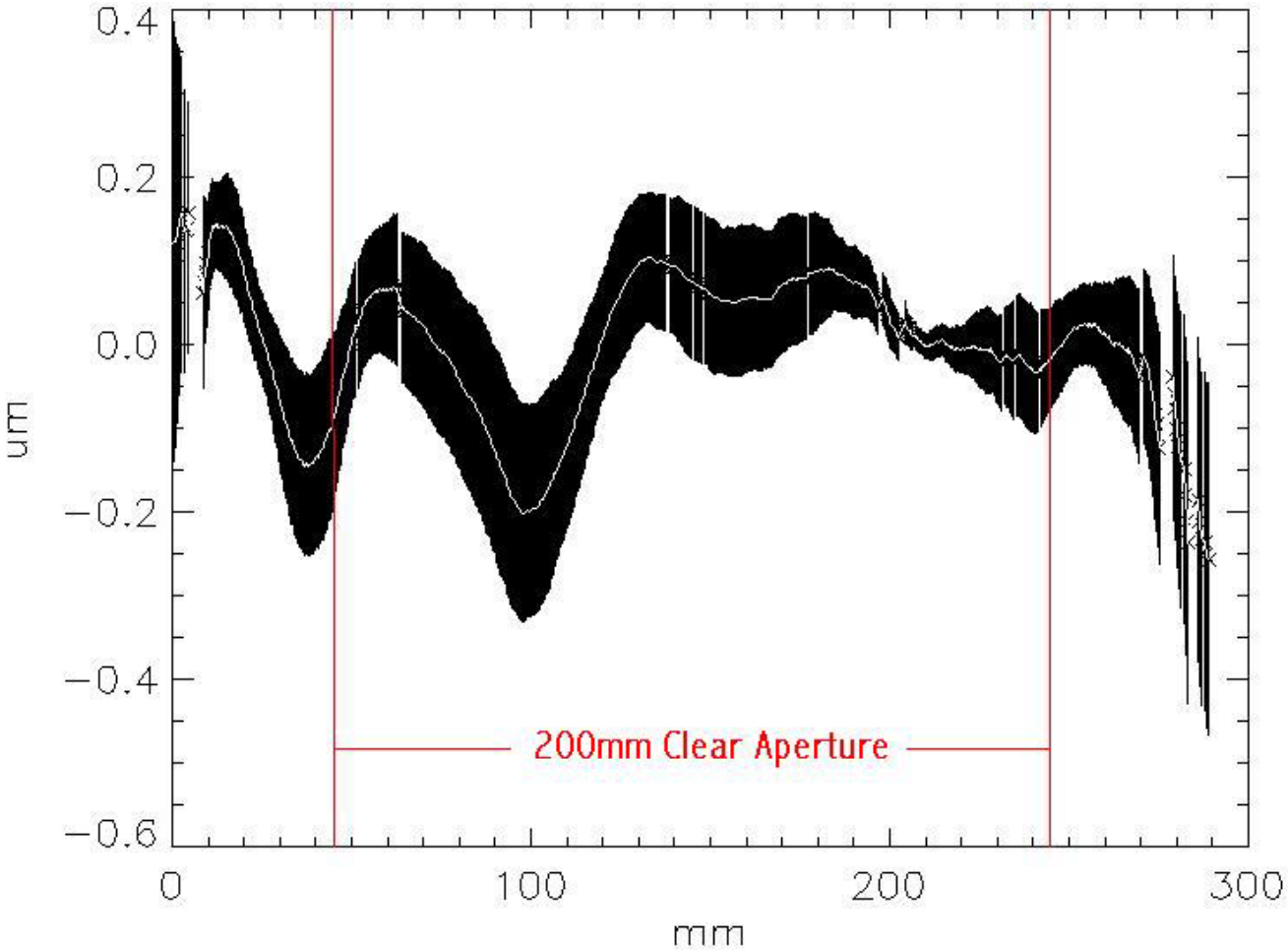
Results: Full Aperture



- **Average of all 12 axial profiles in white**
- **Error bars in black**
- **3.46” RMS slope**
- **-0.45µm P-V sag error**
- **3.29” RMS residual slope error with sag removed**
- **Axial microroughness about 1nm (10Å) RMS**

Axial figure error of mandrel F494S after figuring

Results: Best Quadrant, Clear Aperture

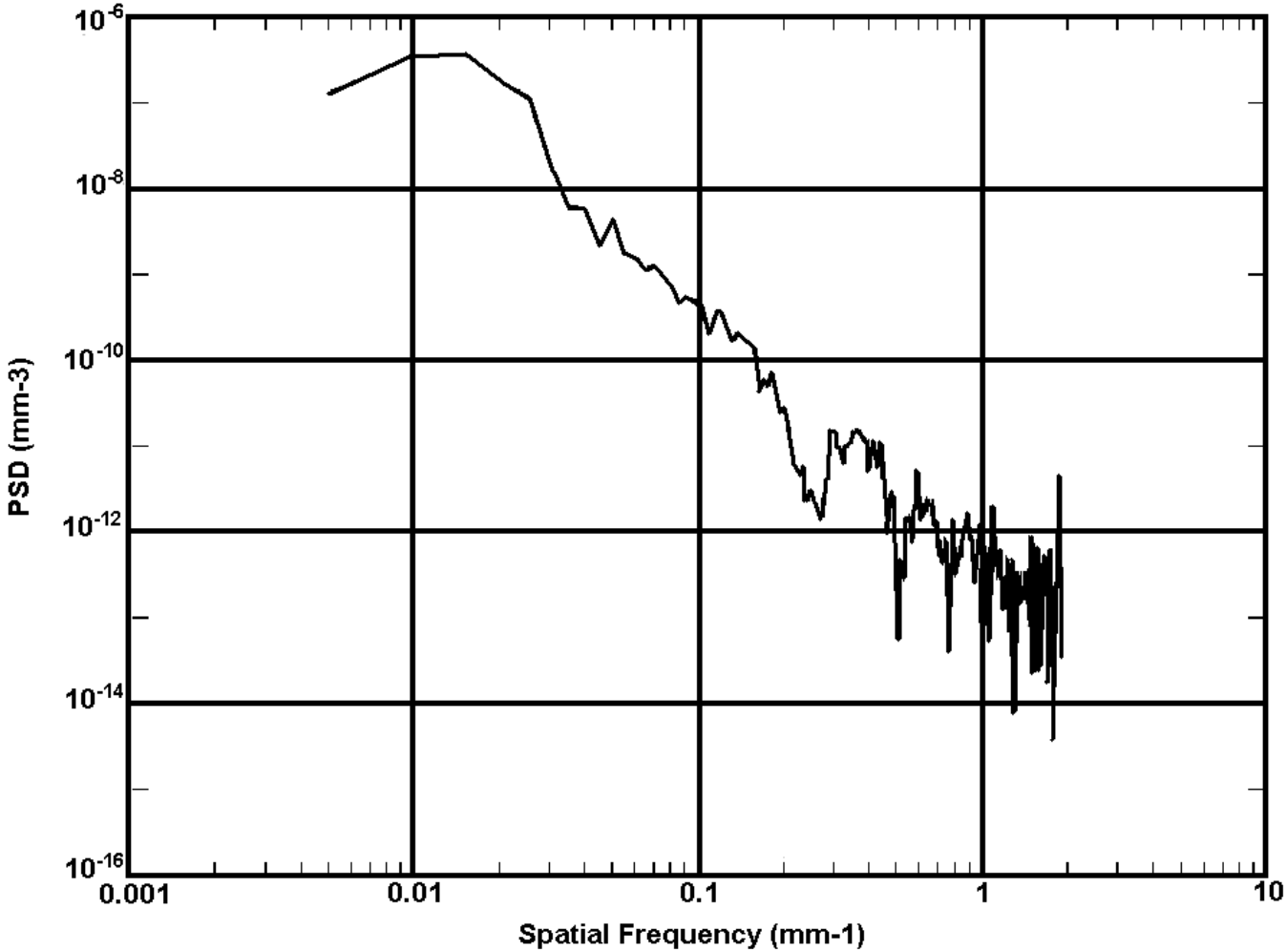


- **Average of 4 axial profiles of best quadrant in white**
- **Error bars in black**

- **1.60” RMS slope**
- **0.08µm P-V sag error**
- **1.59” RMS residual slope error with sag removed**
- **Axial microroughness about 1nm (10Å) RMS**

Axial figure error of mandrel F494S after figuring

Power Spectral Density of F494S



PSD of figure error on F494S

- **Low order Legendre-Fourier polynomials removed**
- **No enhancement of figure errors in troublesome spatial frequencies 0.05 to 0.5 per mm**

What's Next?

- **Figure 4 remaining forming mandrels**
  - F489 primary and secondary
  - F485 primary and secondary
- **Explore new mandrel materials**
- **Develop small tool figuring with axially varying tool dwell time**
  - Machine has full 2 axis control which allows variable speed tool traverse as function of axial and circumferential position
  - Attack small scale errors that full aperture lap doesn't remove
  - Attack non-circular symmetric figures